DIASTROPHISM AND THE FORMATIVE PROCESSES. V

THE TESTIMONY OF THE DEEP-SEA DEPOSITS

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Deposits laid down immediately after a deformation of the earth-shell adjust themselves more or less closely to the new inequalities of surface. This adjustment takes place at any level at which deposition occurs, shallow or deep. This follows from the nature of the case and needs no discussion. But in the stages that follow the deformation at some interval, when cumulative effects begin to be felt, the shaping of the deposits bears larger evidences of the agencies that work from the general environment and that shape into conformity with themselves the new configurations which the bottoms assume in the process of growth. In the preceding articles we have tried to draw out certain diastrophic significances from the nature of deposits laid down on shallow bottoms which, in the process of growth, came sufficiently near the water surface to be given shape by its agitation.

It falls to us now to inquire what diastrophic import there may be in the deposits of the deep sea on which surface agitation has slight effect and to which contributions from the bordering lands are limited. We may then turn to deposits that lie between the deep-sea deposits and the shelf-sea deposits, and that partake measurably of the qualities of both without having the distinctive characters of either.

The deep-sea deposits form a distinctive class sharply distinguished from sea-shelf deposits. They have been made so familiar by the labors of Sir Wyville Thompson, Sir John Murray, and their colleagues of the Challenger Expedition, and by the contributions of Professor Alexander Agassiz, the Prince of Monaco, and others, that we need here dwell only on those features that bear testimony to the nature, extent, and limitations of the diastrophism that has affected them.

By way of approach and qualification let it be noted that while these deposits mantle the bed of the deep sea very generally and must be presumed to have been essentially free from the agitating effects of sea waves and similar superficial agencies, the special locations in which such deposits accumulated most largely were yet somewhat influenced by even such currents as affect the abysmal waters. The larger part of the finely divided material of the abysmal deposits, whether it came from surface organisms or from dust or wash, floated long before it finally found lodgment at the bottom of the deep sea, and hence slight differences of motion determined whether given particles came to rest at a particular point or floated on to a quieter spot. The circulation of the deep sea is relatively gentle, but still there is the circulation actuated by the differences of temperature between the equatorial and polar regions, and the differences of density between the belts of heavy precipitation and the belts of active evaporation, not to speak of motion communicated by friction from the surface currents actuated by the winds, tides, and other familiar agencies. If the great sea basins have been essentially permanent throughout geologic history, a point we shall urge a little later, the long persistence of the currents of the deep circulation have made cumulative differences in the growth of the abysmal deposits, and some fraction, greater or less, of the undulations and the smoothed surfaces that characterize the ocean bottoms signify differences of deposition, even though the deposition at any one time has been small compared with the volume of sedimentation that took place in an equal time near the sea border. It is observed that on many submarine slopes and ridges no fine mud is deposited because of the strong currents that sweep the bottom clear.[1] In the upper half of the ocean depth the movement of the currents has been measured instrumentally; in the lower half, positive data are scant, but it is clear that the diversion of the great abysmal currents of water, as they encounter continental or other obstacles to their progress, is likely to give rise to concentrated or quickened currents at the critical points of arrest and deflection.

But, although such inequalities of deposition must be recog-

[1] Murray and Hjort, *The Depths of the Ocean* (1912), p. 272.

nized, they do not alter the great fact that the abysmal bottoms are mantled almost universally by a characteristic deposit, nor is there ground to suppose that these inequalities of deposition are sufficient to conceal any great deformation that has affected the abysmal bottoms since the earth came to mature form. Mountain ranges, if they once existed on the sea bottom, can scarcely have been seriously obscured by deep-sea deposits, and, if there have been protrusions from the sea bottom of a continental order, their configurations should still be visible.

Among the characteristics of the deep-sea deposits that have diagnostic value in our study are those especially which imply that given deposits must have been formed at given abysmal depths. There is need to consider the following factors:

(1) The relics of life that lived in the surface waters of the clear ocean or within photosynthetic depths or depths that have distinct relations to surface conditions, the pelagic life or plankton. Where the surface life mingled freely with terrigenous silt, as it generally did near extensive land, the silt tells the tale of its relationship. Where the surface life made deposits essentially free from admixture with terrigenous silts, open oceanic conditions are generally implied, but the deposits in themselves do not imply any special depth of sea. They do not even necessarily imply distance from land, for if the set of the ocean currents is constantly and steadily toward the land, the pure oceanic waters may effectively keep back the land silts and give origin to a pure oceanic deposit close up to land. So too, measurably, if currents of pure oceanic waters set steadily and persistently into mediterranean bodies of water, relatively pure pelagic deposits may be formed when the conditions are such that basal and marginal agitation is held in abeyance. When the land has been well base-leveled and is densely clothed with vegetation and bordered by sea-encroaching plants, the conditions are favorable for relatively pure oceanic deposits even in waters that indent or intersect the land. Some of the earlier extravagances in the interpretation of chalk deposits have found a check in considerations of this kind. The measure of shallowness of the bottom in such cases is likely to be revealed by the nature of the bottom life. Submerged platforms, however, when isolated

from all migratory connections with land-girting bottoms of like depth, may come to bear a pure pelagic deposit free from clear evidences of shallow-water bottom life and yet without necessarily implying any great depth.

(2) The relics of the life of the zone that lies below the superficial and photosynthetic zone and above the bottom. Normally the life relics of this median zone, as well as the relics from the surface zone above, fall together to the bottom and are there mingled with the relics of organisms that live at the bottom. Only a part of the mixture is diagnostic of depth, the benthos. A possible source of error of interpretation may arise in those areas in which the lower waters are constantly welling up and so displace the usual surface layer and more or less of its life. This displacement of the surface life is most likely to be effective where the temperature or the salinity of the rising waters is uncongenial to the surface life. In such areas the lower life is likely to follow the rising water to unusual heights and perhaps thus to vitiate more or less the usual bathymetric interpretations.

(3) The relics of the bottom life. In so far as this life is strictly confined to the bottom and can be proven to be limited to given depths, it constitutes a firm criterion for determining the depth at which the deposits containing it were formed. Positive proof that any particular form of life is strictly confined to given great depths is attended by inherent difficulties. In the great depths of the ocean basins there is a complication of the influences that affect living organisms, (1) pressure, (2) temperature, (3) salinity, (4) gas-content, as well as less tangible agencies, and it is improbable that the individual effects of these have as yet been wholly disentangled and the influence of pressure, as such, separately discriminated. *Pressure*, however, is the only true criterion of depth; the associated temperatures, salinities, and gas-contents are incidental; indeed just now they are probably the special results of the present polar phase of the deep-sea circulation; they are perhaps to be regarded as but a lingering feature of the recent glacial period, and as more or less inapplicable to other periods. It would probably be quite unsafe to assume similar temperatures, salinities, and gas-contents at all other times. In the period, for example, during

which life of sub-tropical aspect flourished in the surface seas of polar latitudes, it is not apparent how ice-cold waters could fill the abysmal depths in low latitudes as they do now; nor can similar salinities or gas-contents be safely assumed. The gas-content of the deep-sea waters at present seems clearly to be the result of high absorption in the cold polar regions where the absorption of oxygen is about doubled for a lowering of temperature of 30° C. and the absorption of carbon dioxide doubled for a lowering of about 20° C. I have elsewhere urged that there was a reversal of present deep-sea temperatures at the times when the remarkable stages of polar warmth prevailed, and that the reversal was the cause of such warmth.[1] If such reversal took place, it would probably modify rather radically the gas-content, as, by hypothesis, it did the salinity and temperature of the deep-sea waters, and hence, no doubt, their life. Whether this view be accepted or not, the difficulty of rationally postulating the persistence of ice-cold abysmal water in a stratum lying between the heated interior of the earth and a surface stratum sufficiently warm to sustain reef-growing corals in high latitudes is manifest. It is a much safer assumption that the temperature of the abysmal waters is variable, and has usually followed the climatic episodes that have dominated the earth's temperature in general.

It is almost certain that oceanic life is more responsive to such changes of temperature as occur in nature than to such changes of pressure as it usually encounters. Life is indeed seriously affected by changes of pressure that are so rapidly forced upon it as to prevent a distribution of the pressure increment or decrement throughout the tissues, but organisms do not often suffer such sudden changes in the course of nature. A change sufficiently slow to permit a gradual equalization of pressure seems to be tolerated by sea life with relative indifference. According to Murray and others some species of rather free-moving forms have a bathymetric range of 3,000 meters and more. Some species indeed seem to pass from one pressure to another in short periods without ill effects. The present adaptations of abysmal life may therefore be

[1] T. C. Chamberlin, "On a Possible Reversal of Deep-Sea Circulation and Its Influence on Geologic Climates," *Proceedings of the Amer. Phil. Soc.* (1906), Vol. XLV.

regarded rather as adaptations to existing temperatures, salinities, and gas-contents which happen to vary with depth, than as adaptations to pressure simply. The present distributions of abysmal deposits are therefore probably the products of a complex of variables of which temperature, salinity, and gas-content are not unlikely more potent than pressure.

Deep-sea deposition is at present singularly conditioned by the action of the sea-water. If the surface life were essentially uniform, and if some appreciable amount of life occupied all lower depths, as seems to be the case, the deposits of any period, if unmodified, should increase in thickness with increase of sea depth; but almost the reverse seems to be the real fact. This reversal is assigned to the solvent action of the sea-water. The larger portion of all the life relics assignable to the upper levels is wanting at the greatest depths. It is nearly absent over a large fraction of the abysmal area. The calcareous element is more largely removed than the silicious, but the latter seems to suffer also. This selective action gives to the residue of the extreme abysmal deposits their striking character more largely perhaps than any abundance of life relics that are known to be confined to great sea depths. This solvent action is most plausibly assignable at present to the exceptional absorption of. oxygen and carbon dioxide in the polar seas whence it is carried to all the abysmal depths, giving them at once their low temperature and their high content of these active gases. The sections of Brennecke showing the distribution of oxygen in the North Atlantic between latitude 60° N. and 50° S. are very instructive in this respect.[1] The oxygen acting on organic matter gives rise to carbon dioxide and this, added to the original content, gives competency to dissolve the calcareous shells that fall from above. The loss of the silicious relics is not so well determined nor so well explained so far as it may be a fact.

In interpreting oceanic deposits of other ages than the present, the possibility, if not the probability, that different groups of organisms and different solvent results marked the various bathymetrical horizons, because the gas-contents, the salinities, and the temperatures were probably different, is not to be overlooked.

[1] Murray and Hjort, *The Depths of the Ocean* (1912), pp. 255, 256.

But these prudential considerations do not affect the general diagnostic nature of the oceanic deposits. They only bear on certain special bathymetrical inferences.

It appears from all the considerations that bear upon the case that the diagnostic character of the abysmal deposits is of a most declared and convincing type when broadly applied with due circumspection. Grounds for a critical attitude only arise in respect to ultra-inferences based on small remnants of ancient deposits in limited areas.

Now the broad facts are these: At the present time nearly two-thirds of the area of the earth's surface is covered by deep-sea deposits of recent origin. About one-half of the present surface is covered by truly abysmal deposits. What lies below these abysmal deposits, representing earlier periods, is unknown, because inaccessible. There is a strong presumption that similar deposits lie below the recent ones representing the earlier ages. This presumption rests on the more primary assumption that oceans of great volume existed all through those earlier ages and were giving rise to oceanic deposits, since the requisite forms of life and of débris are known to have then existed, and this, taken in connection with the even more significant fact that such abysmal deposits do not form appreciable members of the terranes of the continents, leaves no other presumption available. Sir John Murray says: "With some doubtful exceptions, it has been impossible to recognize in the rocks of the continents formations identical with those of the pelagic deposits."[1] And again he remarks: "It seems doubtful if the deposits of the abysmal areas have in the past taken any part in the formation of the existing continental masses."[2] With few exceptions, the marine members of the continental deposits belong to the shelf-sea series and to deposits of the foreset terrigenous type. These are facts of the first order of moment, and in them lies strong evidence of the permanence of the continents. The marine deposits of the continents are either epi-continental or terrigenous, the deposits of the ocean basins are oceanic and probably always have been as far back as the record permits us to go.

[1] Murray and Renard, "*Challenger*" *Report on Deep Sea Deposits* (1891), p. 189.

[2] *Op. cit.*, Introduction, p. xxix.

The exceptions, so far as there are any, probably all lie in the disrupted border tracts on the edge of the ocean basins or the borders of the continental protuberances, i.e., on the junction tracts between the great elevations and depressions.

The conclusion that continents and the ocean basins have been permanent in their essentials, thus so strongly supported by stratigraphical and paleontological evidence, is in complete harmony with the modern geodetic argument from the distribution of gravity and with the theory of isostasy, whichever of its phases be accepted. It is, at the same time, consonant with the dynamical inferences that spring from the deep differentiation of the specific gravities of the crust. It falls in with all the views drawn from other sources thus far set forth in this series of articles. Permanent ocean basins, gathering abysmal sediments ever since deep oceans began, alternating with permanent continents, always girt about and overlain by sea-shelf deposits and foreset bordering sediments, are regarded as the great fixed features of the earth's mature history.

The view that the continents and the oceanic basins have been permanent since the earth-body attained its maturity does not of course go so far as to affirm that there were no encroachments of the oceans upon the continents or of the continents upon the oceans, or that there were no transfers of bordering blocks or folds from the one to the other. In the very nature of the case, there must have been pressure contests along the borders, and the dividing lines may well have shifted more or less. Growth and creep seaward from the continents is assumed as probable, and periodic counterthrusts landward from the ocean basins are assumed as more than probable. Advances and recessions on the border lines and oscillations up and down are thus of the nature of the case.

Though the continental segments, because of their lesser specific gravities and their convex attitudes, tended, when under lateral pressure, to upward movement, and the sub-oceanic segments, because of their higher specific gravities and their concave forms, tended, under lateral pressure, to downward movement and underthrust, reversals of these natural movements would be probable in exceptional cases because of the complexity of the conditions; and so continental folds or blocks might well become abysmal, and

abysmal folds or blocks might well become continental occasionally, while, in still other cases, oscillations between the two extremes might arise. It does not militate, in any proper sense, against the view of permanency of the continental and abysmal segments, that there should be these diversities of local action on the hinge lines of the great segments.

Now there are not only simple hinge lines along the junctions of continental and abysmal segments but there are complex hinge areas, as for example areas in which the angles of a pair of continents and also the angles of a pair of abysmal segments approach one another, as the angles of the two Americas and of the Atlantic and Pacific basins, respectively, approach one another in the Antillean region, and as similar approaches are made elsewhere. These "four-corners" of the earth's segmentation are regions of exceptional instability and are affected by unusual seismic and volcanic activities.[1] In these complex hinge areas it is natural that there should be some exceptional behaviors of blocks and folds on the borders of the four contesting segments, or between them. More than that, these seem to be regions in which gigantic hooks, loops, and spits were built out from the continents, because they are regions in which conflicting shore drifts, as well as drifts of a deeper sort, actuated by the profounder currents of the great water bodies, prevailed. All the lands that lie between the massive portions of North America and South America, including Florida, Mexico, the Gulf of California, Central America, the Isthmus of Panama and the Antillean ridges, bear the aspect of gigantic hooks, loops, and spits formed in the progress of the ages between the massive nuclei of the two American continents. A similar aspect is borne by the hooks, loops, and spurs that connect southeast Asia with Australia. Less notable ridges and bridges of a similar kind appear in other junction areas.

Now if these are in reality constructive features of this kind, built out from the primitive continental segments upon the adjacent borders of abysmal segments, they cease to be typical features of either continental or abysmal type; they are rather conjoint products, with dynamic habits of their own, and they are to be interpreted on the basis of their own idiosyncracies.

[1] Chamberlin and Salisbury, *Geology* (1904), pp. 573–75.

These considerations give point to the following observations:

1. The cases in which true abysmal deposits, or close imitations of true abysmal deposits, now appear above the sea-level do not, when all are put together, appear to attain in area so much as one per cent of the total earth surface. So that, even if we assume that all cases plausibly interpreted as abysmal are truly so, the fraction of the crust in which a reversal of the dominant habit obtains is still so small that it cannot be regarded as other than exceptional.

2. So far as my present information goes, all the cases that call for serious consideration as real or plausible instances of the lifting of abysmal deposits above sea-level lie in the notable hinge areas where exceptional instability now prevails and apparently has prevailed far back in geologic history. By far the best of all cases of supposed oscillation between abysmal and subaërial attitudes is that offered by the "oceanic deposits" of the island of Barbados in the Windward group of the Lesser Antilles. To be associated with this in interpretation are the "oceanic deposits" of Trinidad, Jamaica, Cuba, and Haiti, all in the same hinge area between North and South America and between the Atlantic and Pacific basin segments. These additional oceanic deposits have not been as well studied as those of Barbados, but from what is known they seem to hamper rather than strengthen the interpretation that the Barbados deposits are really abysmal. But to this we will return later.

The supposed deep-sea deposits of Sicily are perhaps entitled to rank next to those of Barbados in type and importance. These, like the preceding, are associated with similar deposits adjacent to the Mediterranean on the north and on the south. These, like the collateral deposits of the Antilles, perhaps hamper rather than strengthen a strictly abysmal interpretation of the deposits. But neglecting this, the notable feature of the case is that these deposits lie in one of the most remarkably unstable regions of the globe, the hinge area between the more stable parts of Eurasia and the stable part of Africa. This hinge line has its eastward projection along the ancient Tethys Straits and thus becomes connected with the East Indian tract which also is one of notable instability. The

Nicobar Islands in this tract are isolated much as are the Windward Islands, and bear deposits interpreted as oceanic.

It appears therefore that all the more notable cases of this class are situated on hinge-line areas where notable flexures of the shell have been pronounced features, and where all movements are perhaps to be regarded as of a special order rather than as typical.

If we grant that all these are cases in which the crust has really oscillated from abysmal depths to atmospheric levels, they can scarcely be said to affect seriously the broad conclusion of permanency of the true continents and ocean basins drawn from the absence of abysmal deposits in the continental terranes, and from the probable presence of these beneath the recent accumulations on the abysmal segments.

Returning to the Barbados case, the gist of the local problem is found in (1) a lower deposit unquestionably formed in shallow water, (2) a middle "oceanic deposit," consisting of some beds resembling globigerina ooze and of others resembling radiolarian ooze and "Red Clay"—the group thought to imply a depression to 10,000 or 12,000 feet—and (3) an upper stratum of coralline rock, implying a return to shallow waters, and later (4) an elevation of 1,100 feet above the sea. The series has been made the subject of an elaborate study by A. J. Jukes-Brown and J. B. Harrison,[1] and of shorter papers by G. F. Franks and J. B. Harrison,[2] J. W. Gregory,[3] and J. W. Spencer.[4] The chemical, physical, and biological comparisons of Jukes-Brown and Harrison make distinctly plausible an abysmal descent between the formation of (1) and the formation of (3), during which the oceanic beds were laid down. The island stands by itself and was completely submerged; its uppermost parts are mantled by the oceanic deposit.

[1] A. J. Jukes-Brown and J. B. Harrison, "The Geology of the Barbados," *Quart. Jour. Geol. Soc. London*, XLVII (1891), 197–250; XLVIII (1892), 170–226.

[2] G. F. Franks and J. B. Harrison, "The Globigerina Marls and Basal Reef-Rocks of Barbados," *ibid.*, LIV (1898), 540–55.

[3] J. W. Gregory, "Contributions to the Paleontology and Physical Geology of the West Indies," *ibid.*, LI (1895), 255–310.

[4] J. W. Spencer, "On the Geological and Physical Development of Barbados with Note on Trinidad," *ibid.*, LVIII (1912), 354–67.

After moderate submersion, no land detritus would reach it, for it stood on the windward side of the Antilles and of South America, as the name of the group to which it belongs implies. The only deposits that could well accumulate, after this stage was reached, were those of the oceanic plankton or of the benthos, if it sank so deep. The life relics of a portion of the deposits supports the interpretation that the island actually sank to the benthos zone, but there is the alternative assumption that the benthos life and correlated conditions were carried up to unusual levels by upwelling currents about the island after it reached the stage of moderate submersion. The supposition of an elevated benthos zone might well seem gratuitous, or even an improbable special pleading, if there were not two considerations that seem to force on the case a choice between alternative special pleadings.

1. In the common interpretation it is assumed that a portion of the crust was depressed 10,000 feet or more to reach the horizon of the benthos and then raised again a somewhat greater amount, while the benthos horizon remained stationary. This is a special pleading where all the burden is thrown on crustal dynamics. This may well seem to the dynamic student as inherently improbable as an upwelling of abysmal waters carrying up the benthos zone does to the biological student.

2. On the island of Jamaica oceanic beds occur which likewise imply depression to at least moderate depths; but the summit heights of the island do not seem to have been submerged, and a similar negation seems to be predicable of Cuba and Haiti, though investigation in these cases is incomplete. The summits of none of these three islands seem to be mantled or ever to have been mantled by oceanic deposits as is the case with Barbados; they merely bear such deposits on their flanks. A special pleading that would carry these down to the usual level of the benthos requires a supplementary special pleading to account for the absence of oceanic deposits over the upper levels generally. Careful study of the whole problem is yet a thing of the future, but if this is a representative picture of the case, it would seem to be in the line of the least expenditure of energy and of the highest probability to avoid the extremes on both sides and to assume that an upwelling of the

deep sea-waters about the islands carried the benthol life and conditions to higher levels than they usually occupy now, while crustal oscillations of moderate range met this by adequate depression. This seems to explain at once, and without violence, the decided oceanic phenomena of Barbados and the divided oceanic and insular phenomena of Jamaica and the loftier islands.

But, however this may be, the total import of the distribution, positive and negative, of the deep-sea deposits furnishes a cogent argument against the view that any large part of the abysmal bottoms of the ocean basin has, at any time since the beginning of systematic stratigraphic history, been so elevated as to become a part of the present continents.

The argument has an indirect bearing on the reciprocal view that former continents have been submerged so deeply as to become parts of the present abysmal bottoms. The depression of any great continent to abysmal depths must necessarily have drawn into the cavity it left a great volume of the oceanic waters, and, if there was no reciprocal elevation of the ocean bottom elsewhere—and the preceding argument bears against that—there must have been a lowering of the sea-level about all the continents, with a profound effect on the shelf-sea work. Such profound effects have not been, I think, inferred from the stratigraphical or paleontological record itself. It is very doubtful if they can be successfully superimposed by special pleading. No great movement in any part of the complex oceanic basin can properly be assumed without specifically assigning its consequences in the changes of sea-level implied by it nor without supporting this by stratigraphical facts. Otherwise it is a speculation entertained in negligence of its physical consequences.

The direct adjudication of the hypothetically lost continents lies in a simple appeal to the configuration of the part of the sea bottom involved. It cannot reasonably be supposed that a continent could be submerged so as to completely obliterate its configuration. Its outlines should be still discernible and constitute its credentials. Without these it would seem hazardous to entertain the conception, even if there were not strong presumptions against it springing from other considerations.

There are well-known ridges on the bottoms of the oceans and others of minor order will not unlikely yet be disclosed. It is quite consistent with sound dynamics and a conservative attitude to suppose that these may have once been more bowed, or less bowed, than now, and that they may once have cut the sea surface and constituted linear islands, or land bridges, and have played their part in the migrations of plants and animals, just as present bridges may have been once submerged. And these conservative deformations, together with the oscillations and displacements of the segment borders, seem to be about the limit of probable interchange between the real continents and the real ocean basins. Their dominant feature was, as Dana, Wallace, and others long ago urged, permanency.